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OVERVIEW OF SUPERSONIC CRUISE PROPULSION RESEARCH

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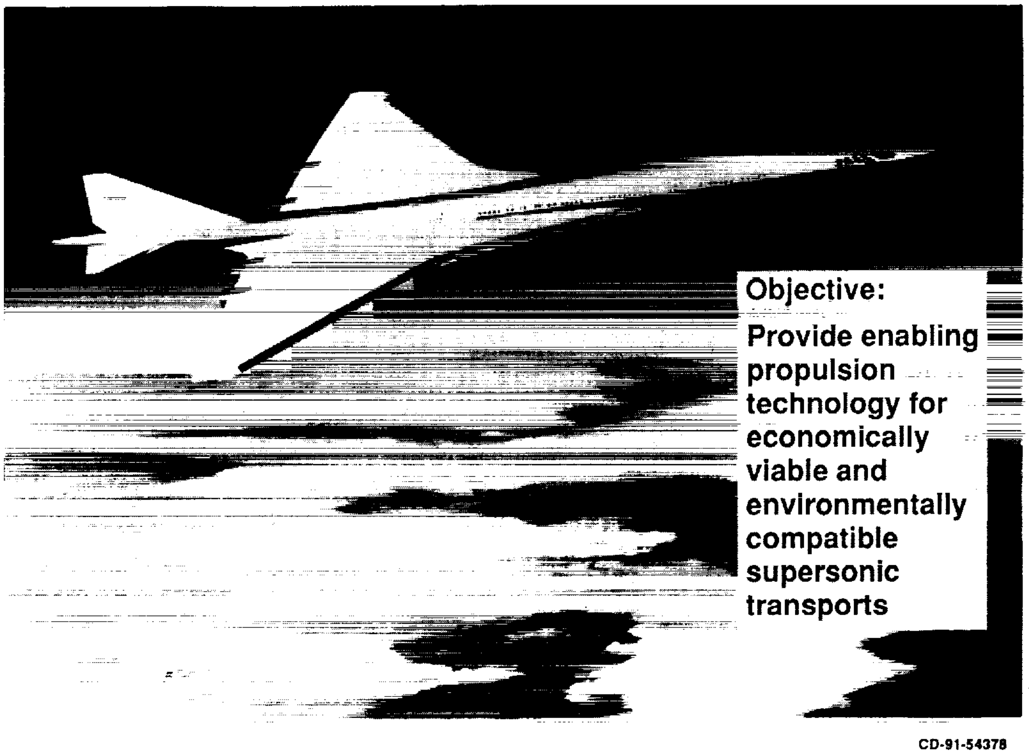
Significant advances in propulsion performance are required if supersonic transport vehicles are to become an important part of the 21st century international air transportation system. The objective of the NASA Lewis Supersonic Cruise propulsion research is to provide the critical propulsion technologies to the industry in a timely fashion to contribute to the design of economically viable and environmentally acceptable high-speed civil transport (HSCT).

Supersonic Cruise



Significant advances in propulsion performance are required if supersonic transport vehicles are to become an important part of the 21st century international air transportation system. The objective of the NASA Lewis Supersonic Cruise propulsion research is to provide the critical propulsion technologies to the industry in a timely fashion to contribute to the design of economically viable and environmentally acceptable high-speed civil transport (HSCT).

Supersonic Cruise Propulsion Research Areas of Emphasis

- **High-Speed Research Program**

  Develop technology solutions to barrier issues of environmental compatibility and economic viability associated with IOC 2005-2008 High-Speed Civil Transport (HSCT)

- **Supersonic Through-Flow Technology**

  Demonstrate viability of supersonic cruise propulsion system based on a supersonic through-flow fan

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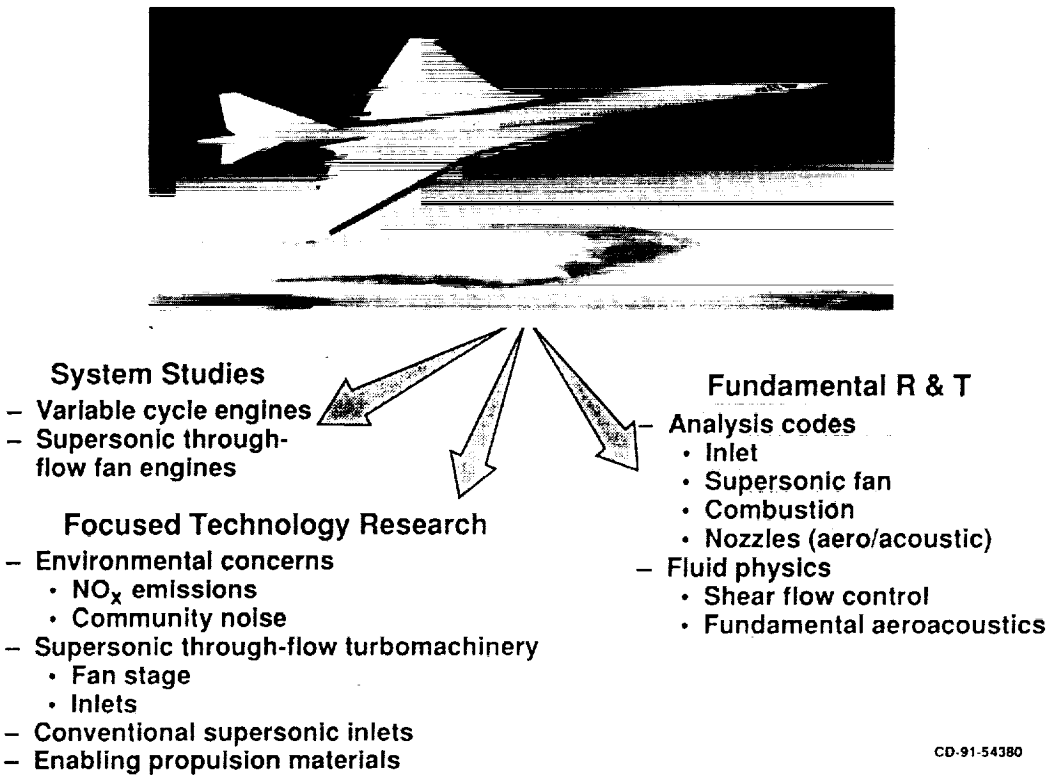
NASA's Supersonic Cruise propulsion research has both a near-term and far-term emphasis. In the near term, the emphasis is on finding viable technology solutions to the barrier issues of environmental compatibility and economic viability. The goal is to have these technologies in place by the end of the decade to allow industry to make a formal "go/no go" decision on producing an HSCT which would begin service in the 2005 to 2008 time period. Efforts are also underway to look at alternate propulsion system concepts that may be attractive candidates for future generation HSCT's. The current long-term emphasis is to develop the technology base for a supersonic through-flow fan propulsion system. This paper will present an overview of both aspects of the Supersonic Cruise research program.

Supersonic Cruise Propulsion Research



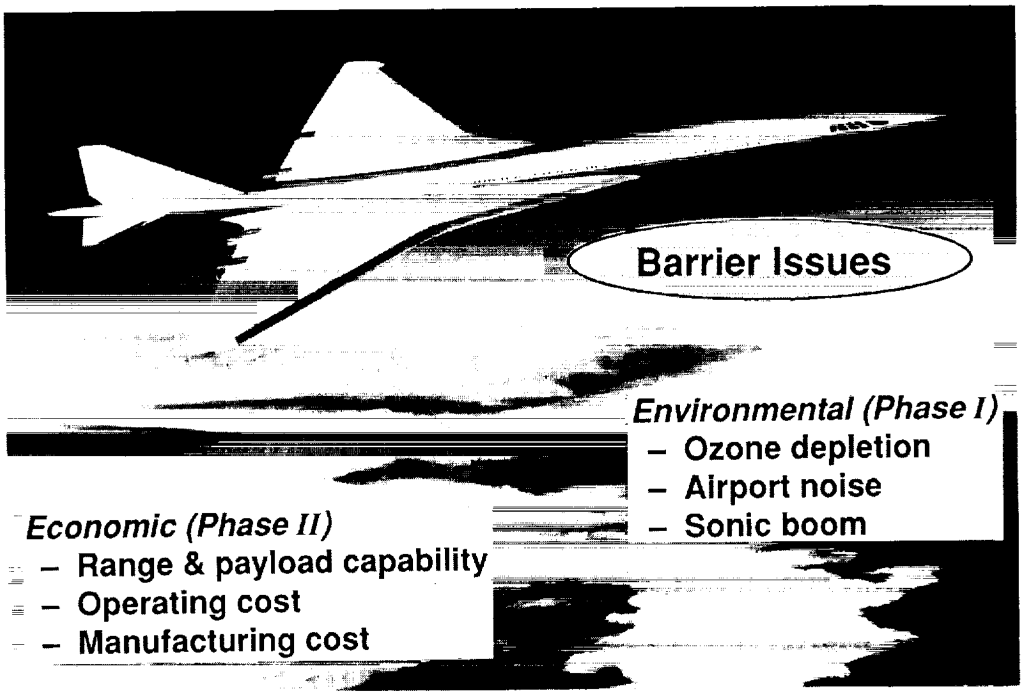
The NASA Supersonic Cruise propulsion research is composed of three major components:

1. System Studies evaluate various candidate propulsion cycles and develop technology roadmaps for the most promising systems.

2. Focused Technology Research represents the dedicated efforts to carry the propulsion research to the required level of development and validation.

3. Fundamental Research and Technology represents the basic efforts required to achieve the goals of the focused technology research.

High-Speed Research Program



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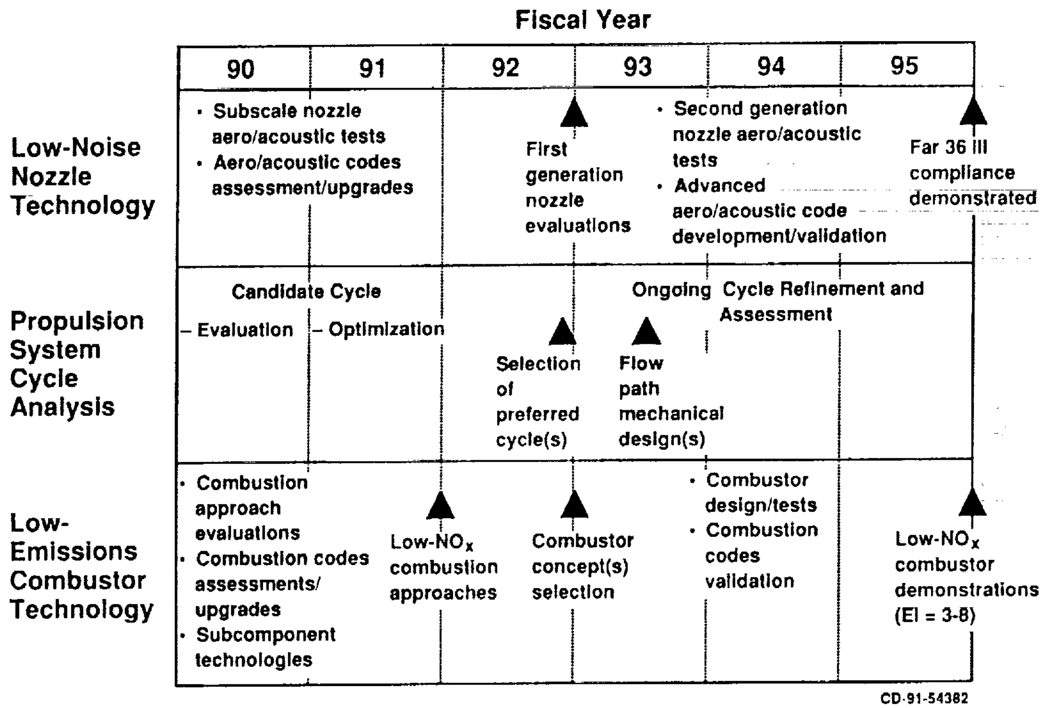
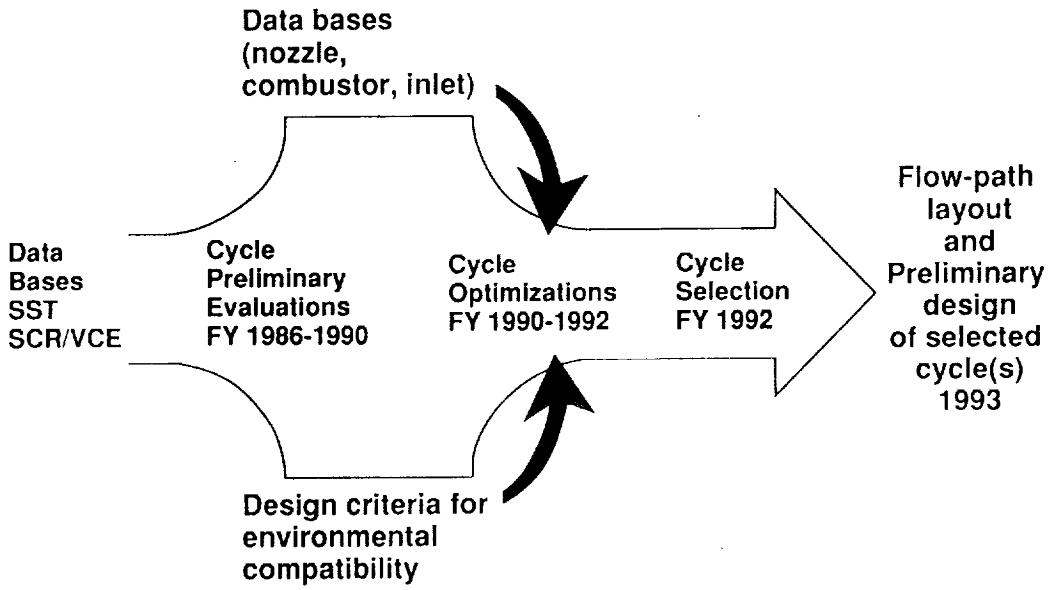
The NASA Phase I High-Speed Research Program (HSRP) emphasizes solutions to the critical environmental barrier issues associated with any future HSCT aircraft. Two of these barrier issues - atmospheric ozone depletion and community noise - are primarily propulsion issues and are addressed in the Lewis portion of HSRP. The critical economical viability issues will be the emphasis of a proposed Phase II HSRP, which could be initiated as early as FY 1992.

NASA Lewis Involvement in High-Speed Research Program



The three elements which comprise the Lewis portion of HSRP Phase I are shown with the major program milestones indicated. Low-noise nozzle and low-NO_x combustor technology efforts will result in scale model demonstrations of component concepts which meet environmental and performance requirements. Concurrent with these component technology efforts are ongoing propulsion cycle evaluations. These evaluations will incorporate the latest component technology data and airframe installation evaluations resulting in the selection of the preferred cycle(s), flow-path layouts, and preliminary mechanical designs. The selection of the preferred cycle(s) will be based on the considerations of environmental compatibility and economic viability. The following charts describe in more detail these three elements of the HSRP Phase I program.

HSCT Propulsion Cycle Evaluation and Selection Process



The propulsion cycle evaluation process is depicted in this figure. The process began with the information from the U.S. Supersonic Transport (SST) and NASA Supersonic Cruise Research/Variable Cycle Engine (SCR/VCE) programs. From propulsion cycles considered during these programs and others more recently conceived, potentially attractive cycles were chosen. They are being evaluated and compared on the bases of environmental compatibility and economic viability.

The factors used to compare and evaluate the candidate cycles include aircraft takeoff gross weight, fuel burn, emissions level and atmospheric impact, and takeoff and landing noise levels.

The cycle evaluation process is iterative and is closely coupled to the propulsion and airframe component technology efforts underway in HSRP. Specifically, as performance results for the various component concepts are acquired, they are factored into the cycle performance predictions and a new round of cycle comparisons is conducted. Other critical input factors include the evolving design criteria for environmental compatibility. The cycle evaluation process is directly influenced by the ongoing ozone impact assessments being conducted in another element of HSRP and by FAA noise certification rules being developed for any future HSCT's.

As the figure indicates, the cycle evaluation process will be conducted through FY 1992. At that time it is envisioned that adequate information will be available to select the cycle(s) which will focus the remainder of the HSRP component and systems integration technology research. For each of the cycles selected, flow-path layouts and preliminary mechanical designs will be completed.

Candidate HSCT Propulsion Concepts

Turbine Bypass Engine	Mixed Flow Afterburning Turbofan
Key Features: – Simplicity – Low cruise combustor temperature	Key Features: – Low jet velocity – Good subsonic SFC
Variable Cycle Engine	**"F" Engine**
Key Features: – Variable bypass – Good subsonic SFC	Key Features: – Variable bypass – Good subsonic SFC – Low jet noise

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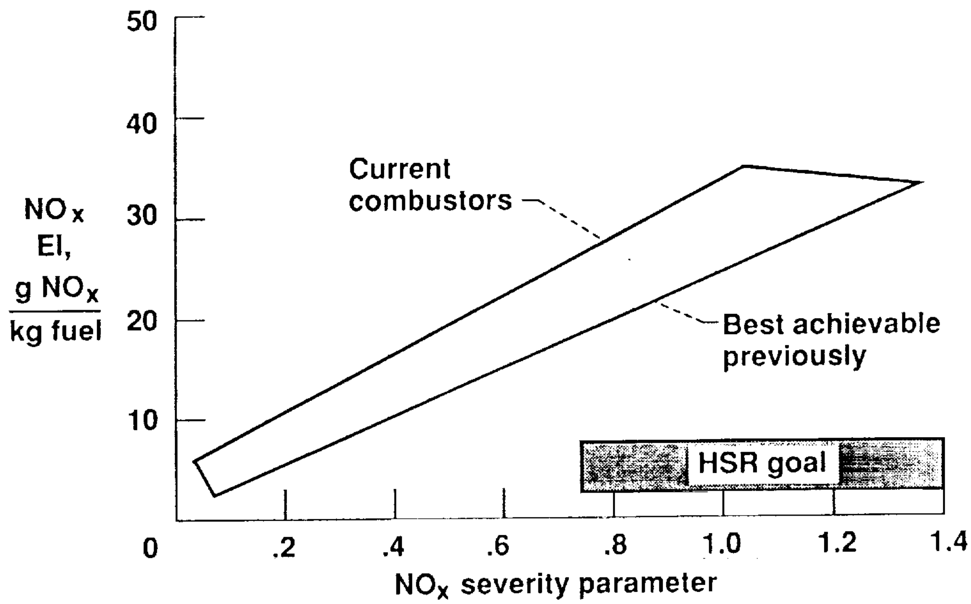
Currently the propulsion cycle evaluation process is concentrating on the four cycles shown. The key features for each of the cycles are indicated.

HSR NO_x Emissions Challenge



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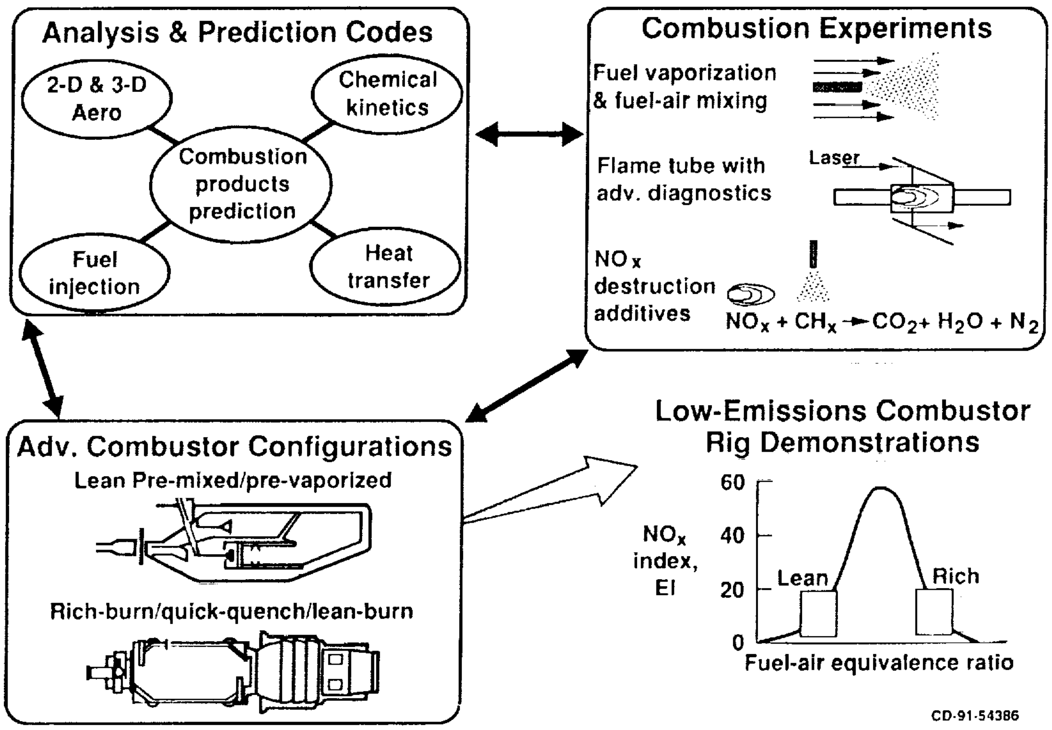
The HSR NO_x emissions challenge is shown in this figure. Initial two-dimensional atmospheric impact studies suggest that ultra low NO_x combustor technology will be required if no adverse impact on the ozone layer is to occur. The standard term for expressing NO_x emissions levels is the emissions index (EI), defined as

$$EI = \frac{g\ of\ equivalent\ NO_2\ produced}{kg\ of\ fuel\ burned}$$

These ultra-low NO_x levels would have EI's in the range of 3 to 8. The figure shows the emissions parameter as a function of a severity parameter, which is itself a function of combustor pressure and temperature levels. The HSRP goal is compared to the performance of current in-the-fleet combustors and to performance levels demonstrated in the NASA/Industry Experimental Clean Combustor Program.

Low-Emissions Combustor Technology Elements



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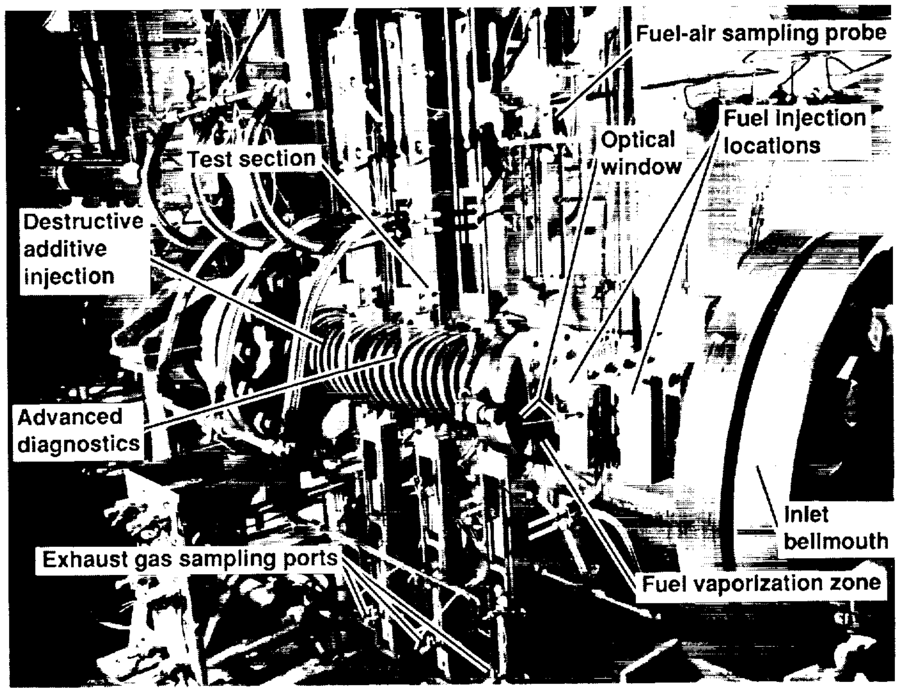
The major elements of the low emissions combustor technology portion of HSRP are shown. Initially, emphasis will be on the development and validation of the computer analyses to predict the details of the combustion process within candidate combustor configurations. Also, laboratory experiments will be conducted to evaluate candidate low-NO_x combustion approaches. These laboratory tests will be used in conjunction with advanced diagnostics to develop a comprehensive combustion code validation data base.

These experimental data bases and the analytical prediction codes will form the basis for the conceptual design of candidate low-NO_x combustors. The deliverable of this element of HSRP will be the demonstration of ultra-low-NO_x combustor configurations in rig demonstrations.

Currently, two combustor concepts appear to hold promise for meeting the HSRP emissions goal of EI = 3 to 8: the lean-premixed-prevaporized (LPP) and the rich-burn/quick-quench/lean-burn (RQL). The key to achieving ultra-low-NO_x production levels is to accomplish all burning away from stoichiometric conditions. The LPP concept features burning at lean fuel-air conditions. The RQL concept requires two stages of burning. The first stage burning is conducted in a fuel rich environment. The transition from rich to lean burning is accomplished through an introduction of quench air between the two stages. The quench air must be introduced into the combustion stream so that mixing occurs rapidly and uniformly such that no localized burning zones occur at close to stoichiometric conditions, which would significantly increase the NO_x produced.

HSR Square Flame Tube Rig
Lean-Premixed-Prevaporized Combustion (LPP)



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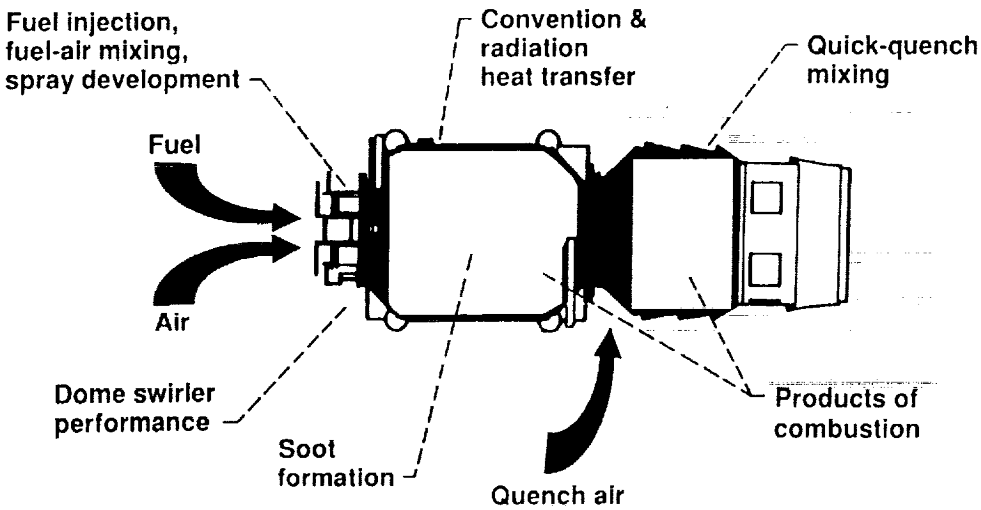
The lean-premixed-prevaporized (LPP) flame tube rig is shown with the key facility characteristics indicated. A similar rig will shortly be operational to evaluate the RQL combustion concept.

Computer Modeling Requirements for HSCT Combustors



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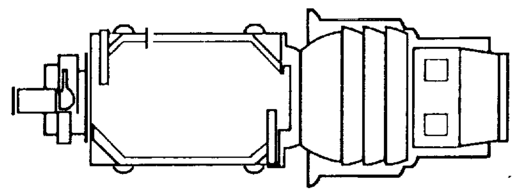
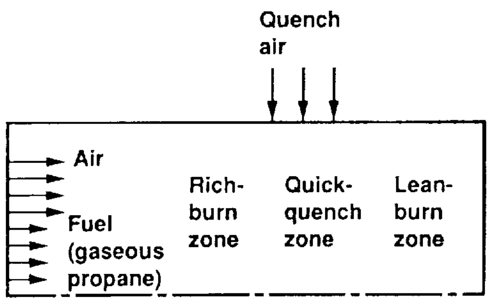
The computer modeling requirements for HSCT combustors are shown here. To be a useful analysis and design tool, combustor modeling codes must be able to predict the critical physics of combustor flow fields as depicted.

Low NO_x Combustor Analysis





Simplified Combustor Model

Predicted Temperature Contours

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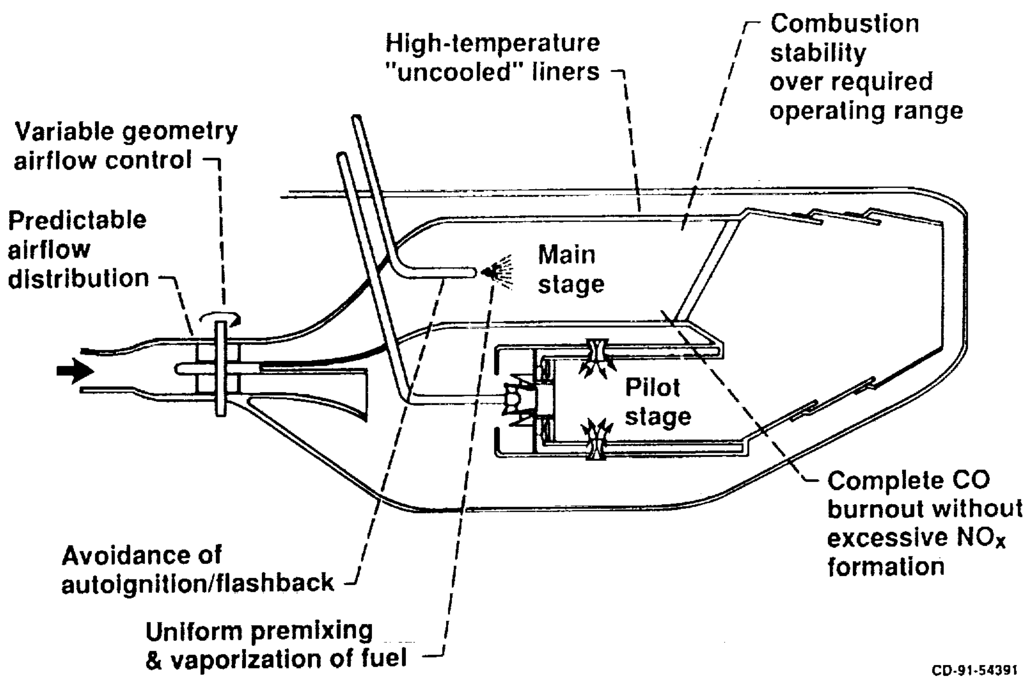
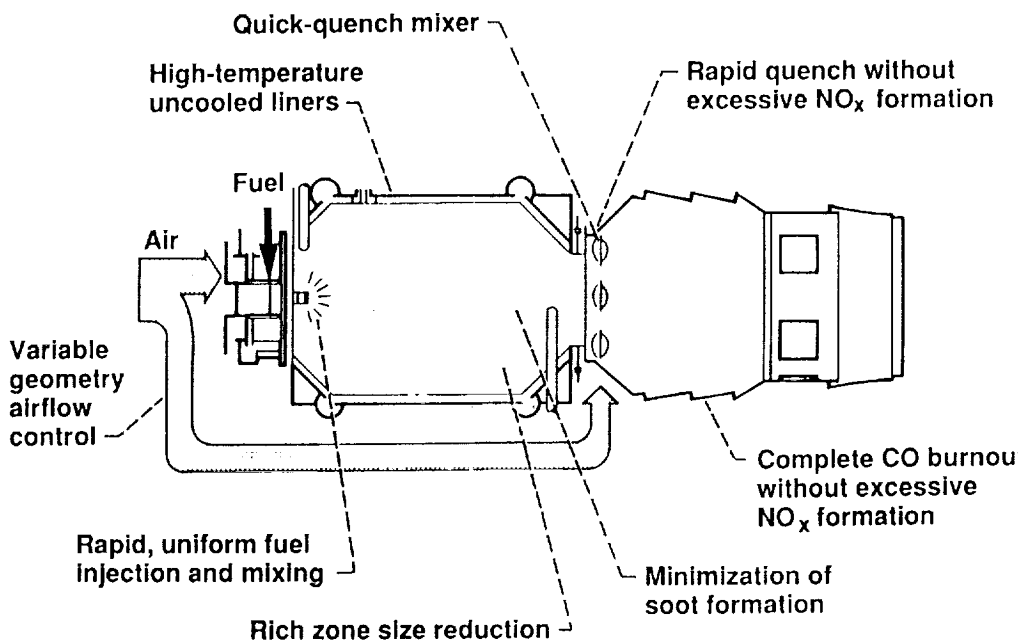
The approach being followed in HSRP is to take existing available computer codes and upgrade, modify, and validate them for HSRP applications. The two codes being emphasized to analyze low NO_x combustors are the KIVA II code developed by Los Alamos and the Lewis Research Center Code (LeRC 3D) developed as part of the NASA rotary engine program. This figure depicts an early attempt to model the RQL combustion process wherein the geometry being considered is an idealized axisymmetric configuration. Temperature contours are shown although velocity and pressure contours are also predicted as are important species such as NOx concentration contours. Both codes are undergoing extensive upgrades to include improved grid generation, turbulence modeling and chemical kinetics. The codes are also being applied to the critical combustor subcomponent problems such as dome swirlers, fuel injectors, and quick-quench mixers. The deliverable from these efforts will be a series of codes sufficiently calibrated and validated against experimental data that they can be used as a part of the actual combustor design process.

Technology Issues – LPP Combustors



This figure indicates some of the critical technology challenges that must be overcome before ultra-low-NO_x LPP combustors could be designed.

Technology Issues – RQL Combustors



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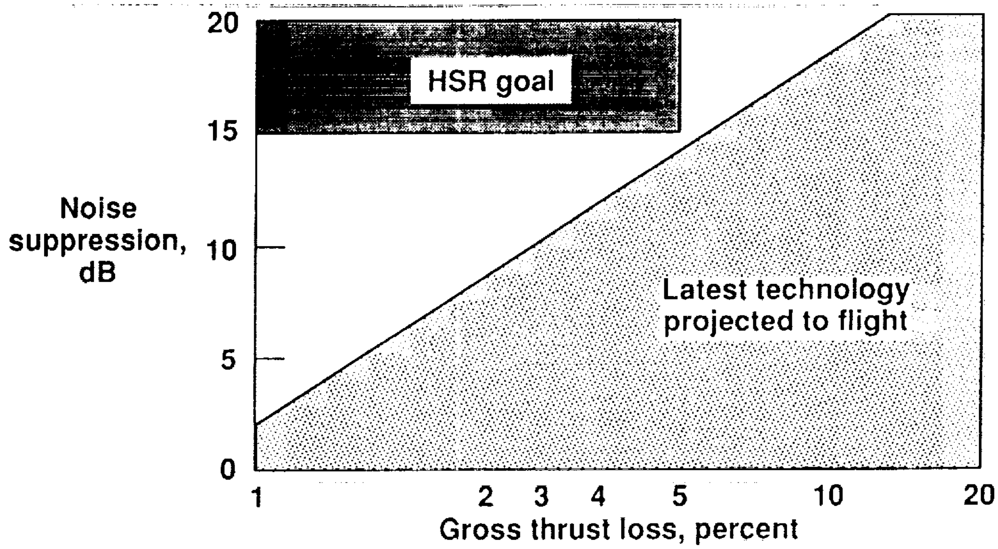
This figure indicates some of the critical technology challenges that must be overcome before ultra-low-NO_x RQL combustors could be designed. HSRP combined experimental and analytical efforts will develop the required combustor subcomponent technologies for LLP and RQL combustors and incorporate them as required in the combustor rig demonstrations at the conclusion of the program.

HSCT Source Noise Challenge



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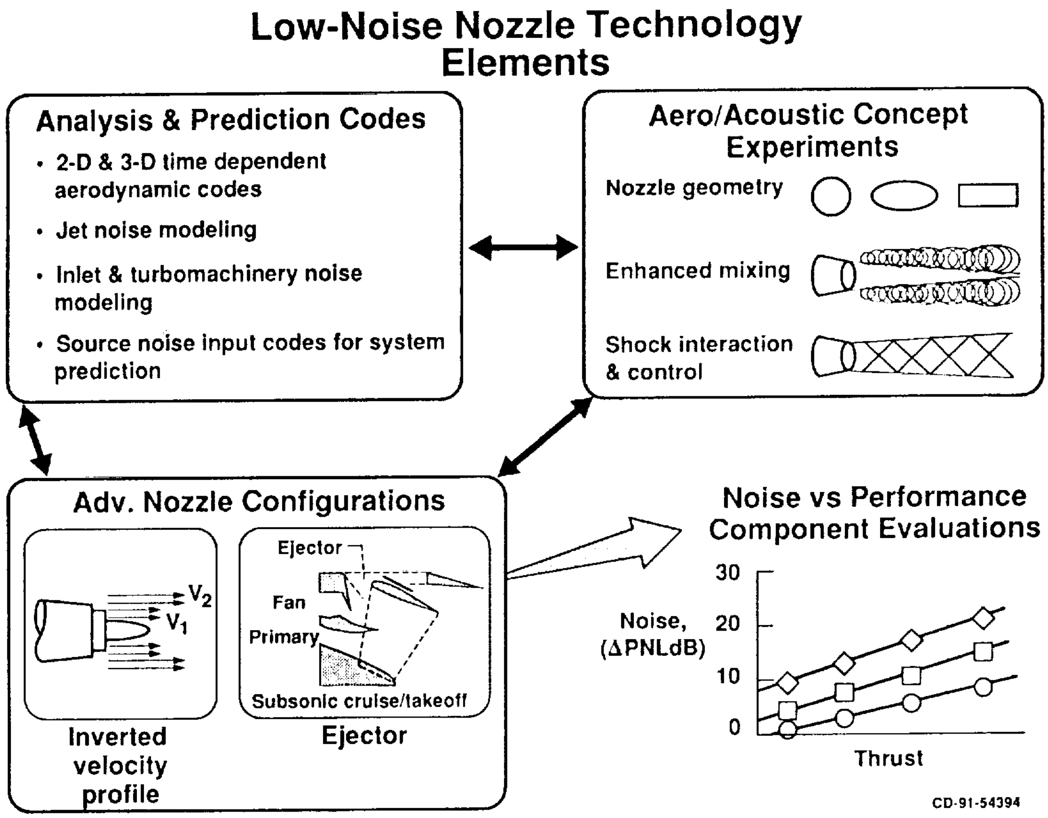
The HSCT source noise challenge is illustrated in this figure. The jet exhaust noise levels at takeoff and landing conditions must be reduced by 15 to 20 db relative to reference conic nozzle levels before any future HSCT can hope to have noise levels below FAA noise regulation limits. At the same time, the nozzle aerodynamic performance levels must be kept high if vehicle overall mission performance goals are to be met. This combined acoustic-aerodynamic challenge is often expressed as a ratio of decibel noise reduction to resultant percent thrust loss. For a viable HSCT design this ratio should be in the neighborhood of 4:1. As this figure shows, current technology would yield a nozzle design with a ratio of no better than 2:1.



The major elements of the source noise portion of HSRP are shown in this figure. Much like the low NO_x combustor area, heavy emphases are being placed in the first years of HSRP on computer code development and validation and on subscale experiments to evaluate potentially attractive nozzle concepts. The emphases regarding the codes is again on applying available solvers for both nozzle aerodynamic flows and for the acoustic signatures of the various configurations. The laboratory experiments and computer code developments and the insights they provide as to the governing fluid physics will be key inputs to the development of advanced nozzle configurations that will meet the HSRP goals, both for aerodynamic performance and acoustic suppression.

Two-Dimensional Mixer-Ejector Nozzle in NASA Lewis 9x15 LSWT

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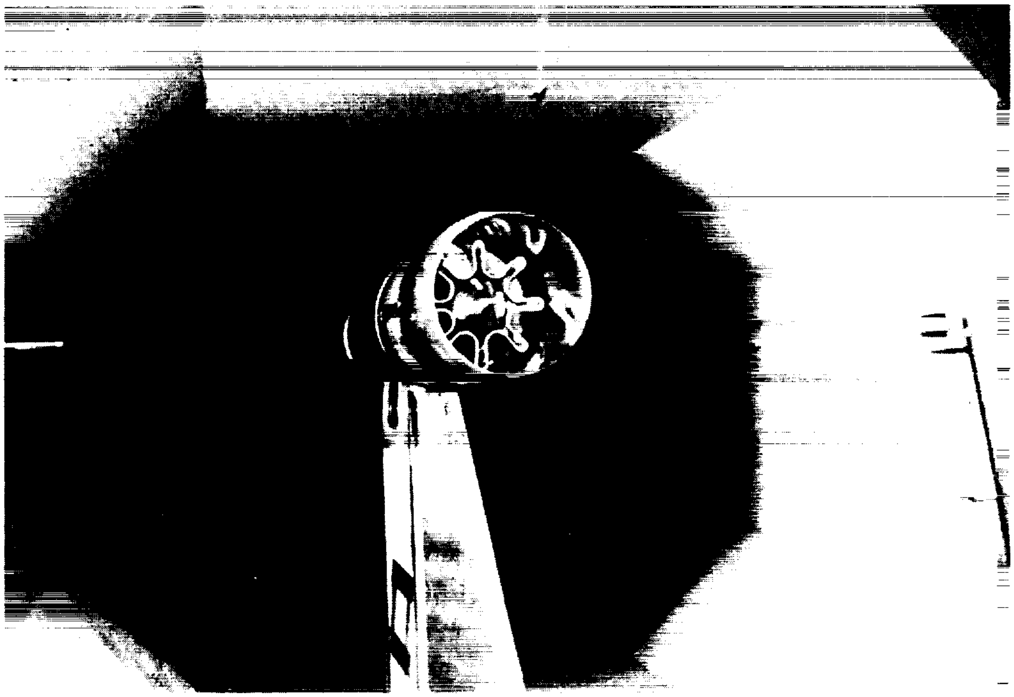
This figure shows a two-dimensional model tested in the NASA Lewis 9 x 15 Low-Speed, Anechoic Wind Tunnel (LSWT) to evaluate a Pratt and Whitney mixer-ejector nozzle concept. Aerodynamic flow field surveys as well as near-field acoustic signatures were made for a series of configurations.

Pratt and Whitney Axisymmetric Mixer-Ejector Nozzle in Boeing Low-Speed Aeroacoustic Facility



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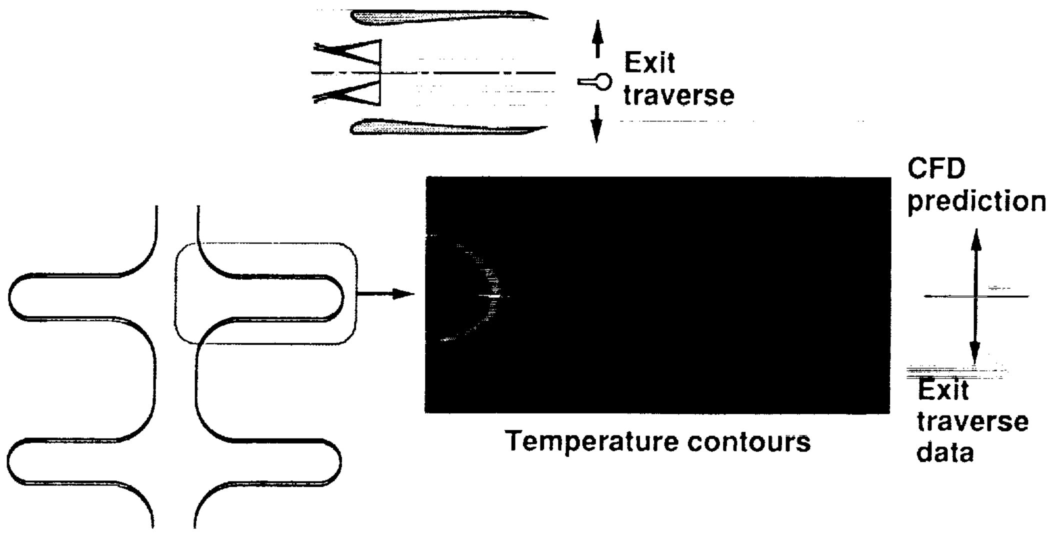
The data from the two-dimensional concept model test in the 9x15 LSWT were used to help in designing an axisymmetric mixer-ejector nozzle configuration. This model was tested in the Boeing Low-Speed Aeroacoustic Facility (LSAF) to measure nozzle aerodynamic performance and acoustic signatures.

CFD/Translating Probe Comparison and Mixing



- Good mixing
- CFD ⟵ ⟶ Exit traverse: Excellent agreement

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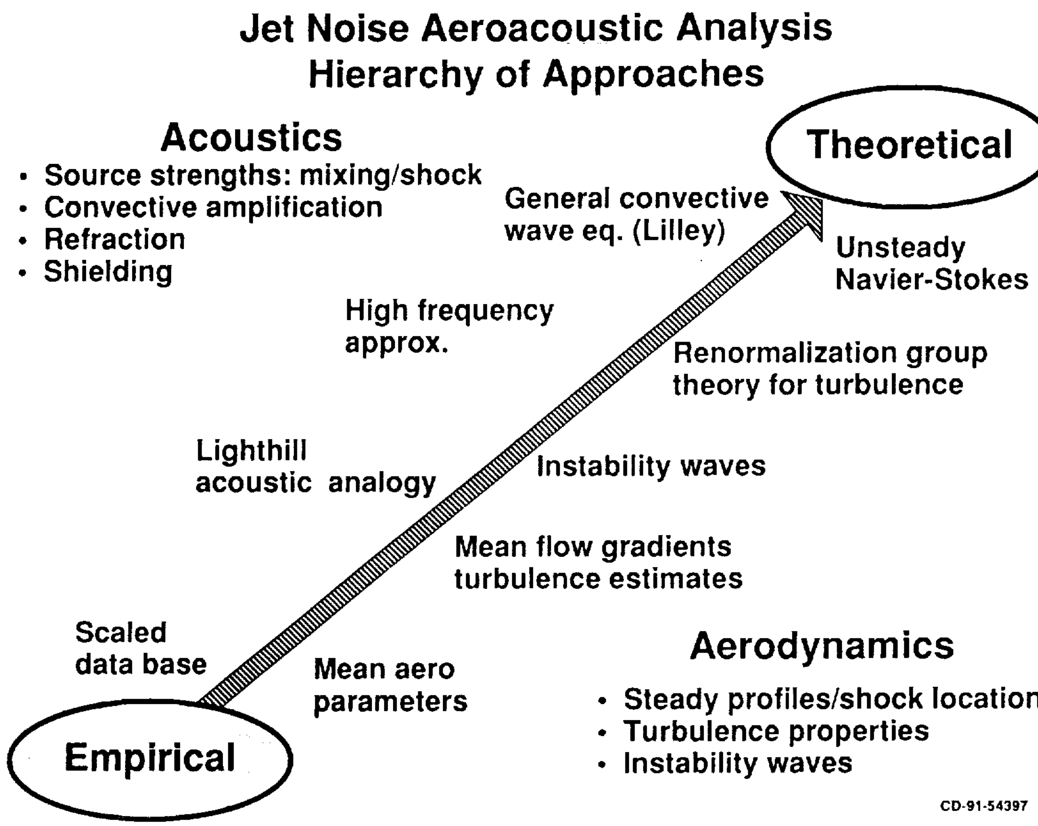
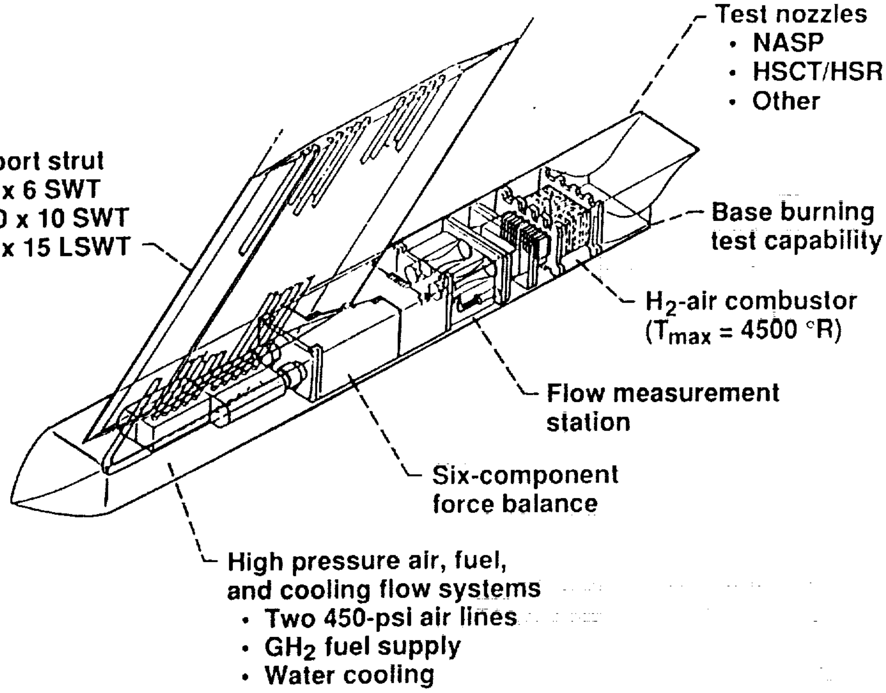
The data from both the two-dimensional and axisymmetric model tests are being compared with Navier-Stokes solver predictions of the nozzle aerodynamic flowfields. This figure shows a comparison of measured and predicted total temperature profiles at the exit of one of the two-dimensional model configurations. The comparison is judged to be excellent. Results such as these suggest the important role computer codes will have in the analysis of nozzle complex aerodynamic flow fields.



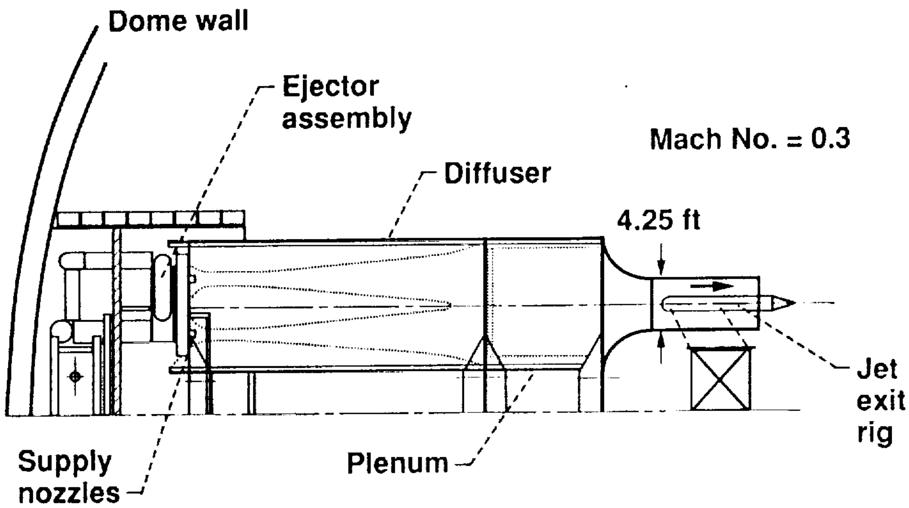
A hierarchy of approaches is being followed to predict HSCT nozzle acoustic signatures. Currently available tools are largely empirical, and these approaches are being updated with the extensive data base being acquired in HSRP. The rapidly increasing computer power available offers the opportunity to develop more fundamentals based prediction schemes for jet noise. Several investigators are pursuing those approaches as part of HSRP.

Jet Exit Rig Details



Advanced experimental test capabilities are being developed as part of HSRP to allow the extensive testing of the many nozzle configurations that will be required to meet the HSRP goals. This figure shows the Lewis Research Center jet exit rig which will be used to test HSRP nozzles for both aerodynamic and acoustic performance. The jet exit rig will be used in all Lewis facilities (8x6 and 10x10 supersonic wind tunnels and the 9x15 low-speed anechoic tunnel) and the NASA Ames 40 x 80 wind tunnel; thus it will be the centerpiece of the experimental portion of the low-noise nozzle technology efforts of HSRP.

Nozzle Acoustic Test Rig (NATR)



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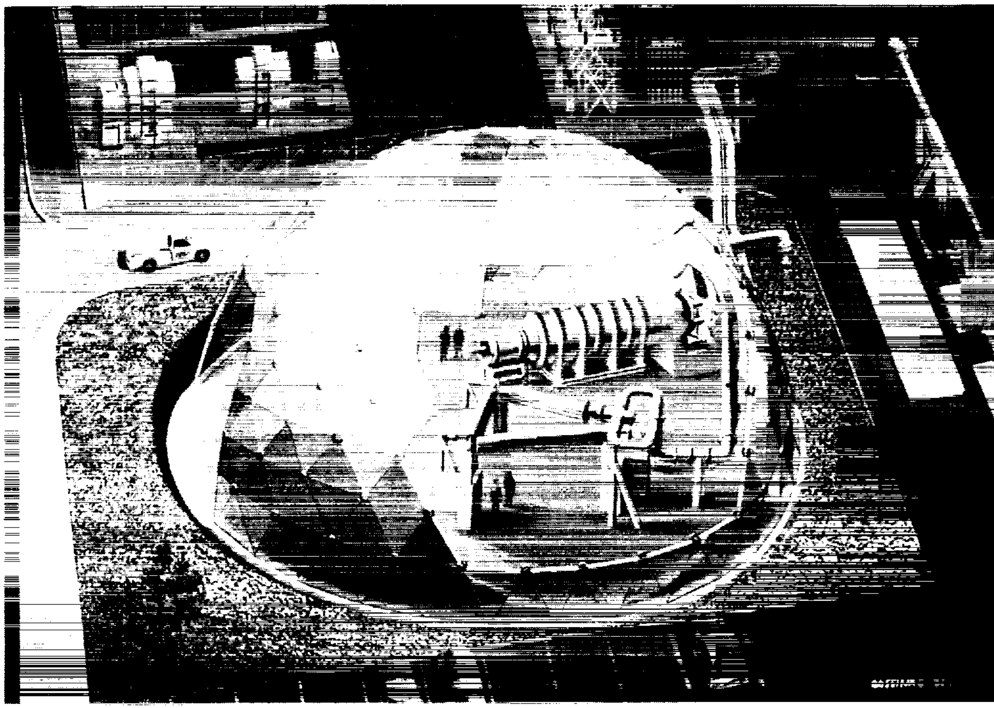
The extensive amount of nozzle low-speed acoustic testing which will be required in HSRP has resulted in the design and fabrication of a free jet test capability called the nozzle acoustic test rig (NATR) at NASA Lewis. The NATR will simulate forward flight conditions at takeoff and has been designed to be compatible with the jet exit rig already discussed.

Powered Lift and Nozzle Acoustic Rig Test Facilities
(Enclosed by geodesic dome)



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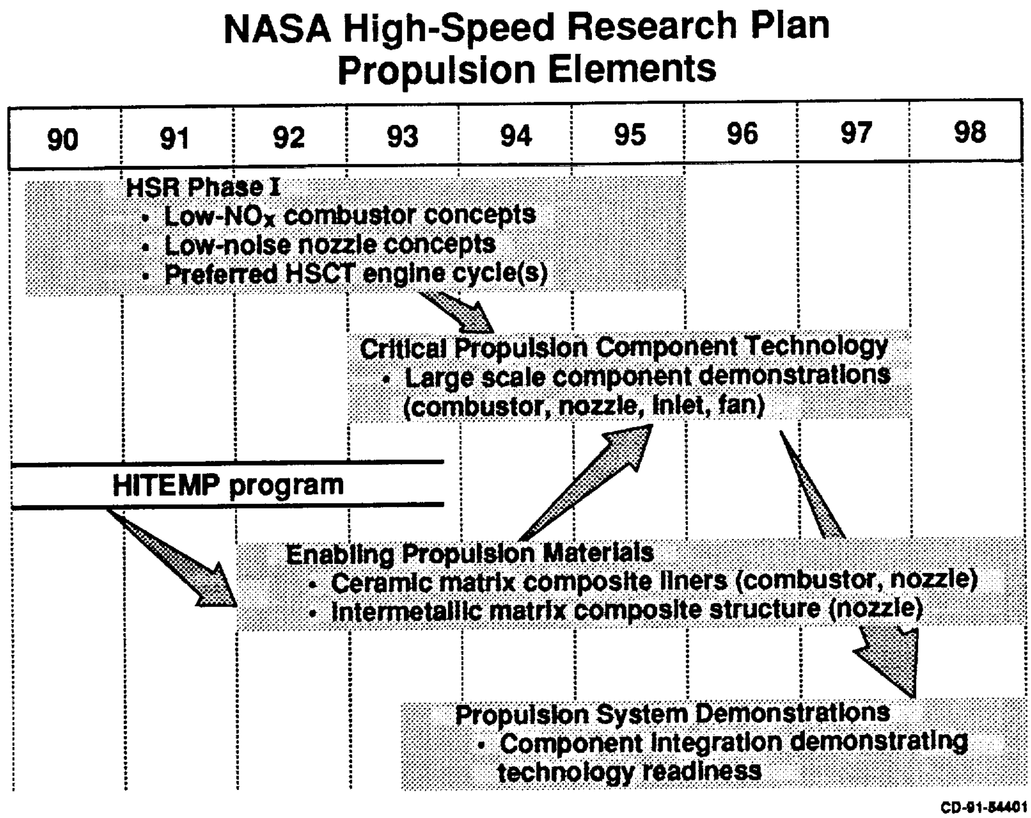
The nozzle acoustic test rig will be located adjacent to the Powered Lift Facility (PLF) at NASA Lewis. In order to alleviate community noise problems and to allow year-round testing, the facilities will be enclosed in a 65-foot-diameter geodesic dome. This figure shows the final version of the design. Appropriate acoustic treatment will be placed in the inside of the dome to allow meaningful HSRP nozzle noise measurements to be made.



The roadmap for the propulsion elements of NASA's overall High-Speed Research Program is shown in this figure. HSRP Phase I efforts will result in demonstrations of low-NO_x combustor and low-noise nozzle concepts as well as determination of preferred HSCT propulsion cycles. NASA's HITEMP engine materials program will provide the basis for the development of the advanced composite materials required for the combustor and nozzle components of any future HSCT engine.

The HSRP Phase I and HITEMP research results will be the inputs to the proposed HSRP Phase II Program currently advocated by NASA. The propulsion elements of HSRP II would demonstrate HSCT propulsion technology readiness initially through large-scale testing of the critical components (inlet, fan, combustor, and nozzle); then these components would be combined with an available core engine in propulsion systems technology demonstrations at both low-speed (takeoff) and high-speed (supersonic cruise) conditions.

The Enabling Propulsion Materials of HSRP II would demonstrate the materials technology readiness through tests of an uncooled ceramic matrix composite (CMC) combustor liner and a nozzle substructure element fabricated from an advanced intermetallic matrix composite (IMC) developed in HSRP II.

Supersonic Through-Flow Technology Program

Objective:

Establish supersonic through-flow technology enabling revolutionary improvement in high-speed aircraft

Focus:

Conduct analytical/experimental research to demonstrate the performance potential of supersonic through-flow compression

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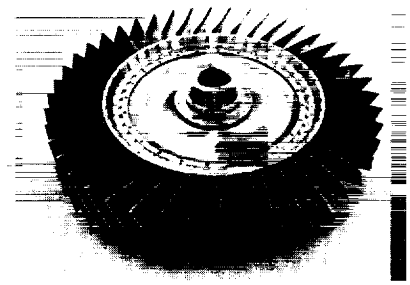
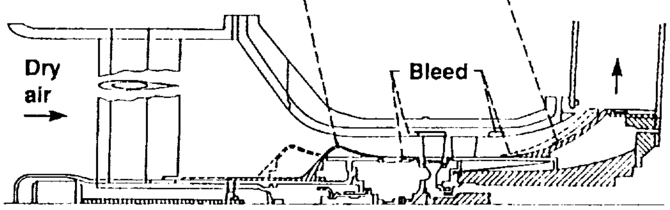
The long-term emphasis in the supersonic cruise propulsion research is on examining alternate high performance propulsion system concepts and pursuing the appropriate critical component and system technologies. Currently, the emphasis is on developing the supersonic through-flow technology and, in particular, on demonstrating the viability of the critical components (fan stage, inlets, and nozzle) and eventually system performance and control across the speed range.

Supersonic Through-Flow Program
Baseline Fan

Goals:
Prove concept of a supersonic through-flow fan stage demonstrating subsonic, transition, and supersonic performances; obtain detailed flowfield mapping for code validation



Pressure ratio	2.45
Inlet axial Mach number	2.00
Rotor tip speed	1500 ft/sec
Tip diameter	20 in.



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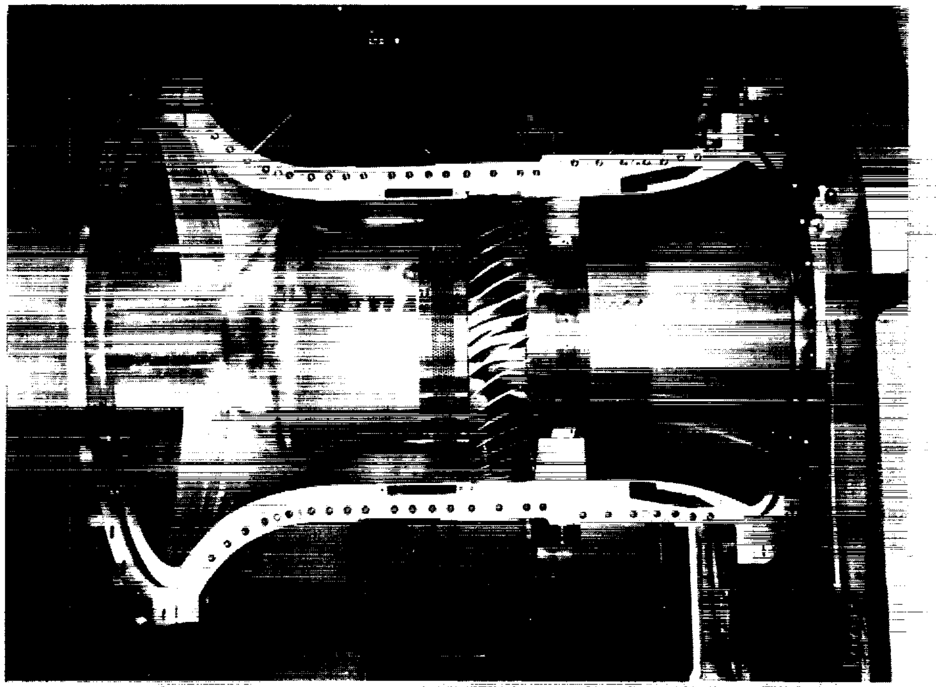
A baseline fan stage is currently being tested at NASA Lewis to demonstrate the viability of establishing and maintaining supersonic flow through a turbomachinery stage. Detailed flowfield mapping experiments will also be conducted, the results of which will be used to validate the various computer codes used in the design and analysis process.

Supersonic Fan Test Section



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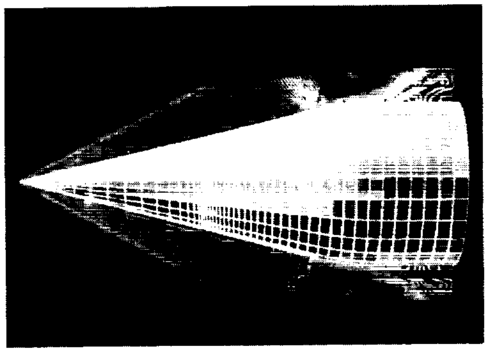
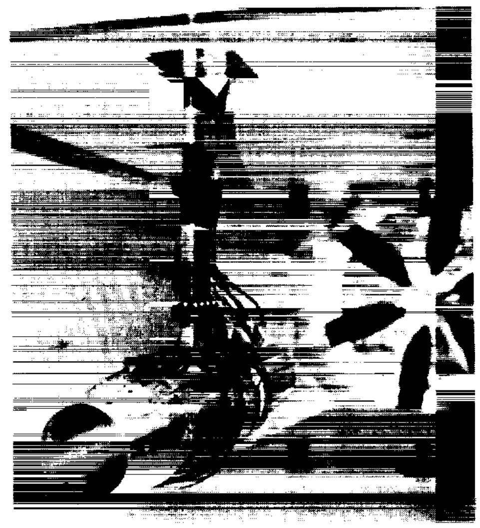
The photograph of the supersonic fan test section shows the rotor and stator blades installed and also the hub and tip bleed regions, which can be used to vary the incoming boundary layer profiles to the fan stage.

Supersonic Through-Flow Inlet Technology





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Currently underway are experimental and analytical studies of inlet concepts that would be appropriate for a supersonic fan. To the small-scale inlet tests being conducted at low- and high-speed conditions, the advanced Navier-Stokes flow solvers were applied to predict the inlet steady-state and dynamic performance characteristics. Similar combined analytical and experimental efforts will be started in FY 1991 to investigate aft inlet and fan nozzle concepts.

Concluding Remarks

- Supersonic cruise propulsion research is a growing part of NASA aeropropulsion program.
- Research efforts have both near- and far-term emphases
  - "Near term" to support IOC 2005 to 2008 HSCT
  - "Far term" to demonstrate viability of supersonic propulsion system based on supersonic through-flow fan.

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Supersonic cruise propulsion research is a growing part of NASA's aeropropulsion program and is poised to provide the propulsion technologies required to maintain U.S. leadership in the international aerospace market in the 21st century.